

The Influence of Buoyancy and Stratification on Circulation, Mixing, and Bottom Stress in Complex Channel/Tidal Flat Systems: A Process Oriented and Realistic Numerical Modeling Study

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Award Number: N000140910396

LONG-TERM GOALS

This effort represents a step towards understanding the dynamics that drive the circulation in estuarine, tidal flat and inner-continental-shelf coastal environments with complex bathymetry and strong forcing by tides, river flow, wind and waves and determining how these circulation patterns and their variability control the pathways of transport of waterborne materials – including sediments, nutrients and anthropogenic materials – through these regions and into the adjacent coastal ocean. Specifically, we aim to develop realistic, high-resolution numerical simulations of such environments that resolve the bathymetric variability and are capable of simulating small-scale coherent structures (for example, flow separation, eddies, and secondary flows) that regulate dispersion and transport of materials within these systems. Essential to this effort is validating such models through skill assessment via statistical comparisons between model output and field measurements over a broad range of forcing conditions.

OBJECTIVES

The principle objective of this effort is to develop a high-resolution numerical simulation of the Skagit River delta (Fig. 1), in Puget Sound, Washington – a complex region with broad tidal flats and complex channel networks and one of the focal systems of the ONR Coastal Geosciences Tidal Flats Departmental Research Initiative (DRI). Our specific objectives are to use this numerical model to:

- Determine the temporal (tidal and sub-tidal) and spatial variations of buoyancy and stratification and their dependence on freshwater discharge, tidal amplitude, and wind forcing.
- Quantify the roles of tides, buoyancy forcing, and winds in driving the three-dimensional circulation within channels and over tidal flats under different forcing regimes.
- Understand how buoyancy, buoyancy fronts, and barotropic fronts regulate vertical mixing and bottom shear stresses within channels and over tidal flats and how these control sediment suspension, transport and deposition patterns.
- Determine the spatial scales of coherent tidal and subtidal circulation structures (e.g., eddies, fronts and instabilities) and how these control transport and dispersion of waterborne materials.

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 2009		2. REPORT TYPE Annual		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE The Influence Of Buoyancy And Stratification On Circulation, Mixing, And Bottom Stress In Complex Channel/Tidal Flat Systems: A Process Oriented And Realistic Numerical Modeling Study			5a. CONTRACT NUMBER		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S)			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Oregon State University, College of Oceanic and Atmospheric Sciences, 104 COAS Admin Bldg, Corvallis, OR, 97331			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES code 1 only					
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15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 4	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

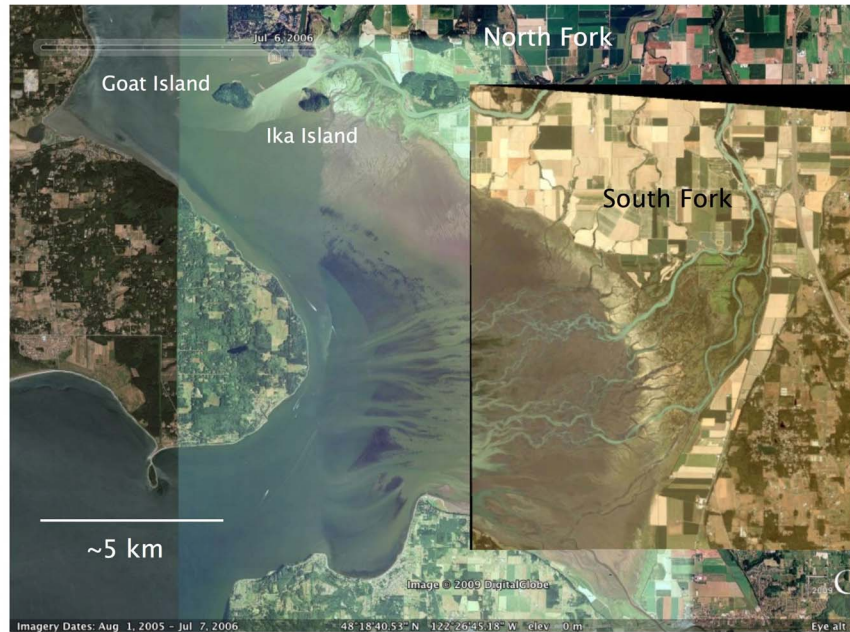


Figure 1. Aerial photo of the Skagit River delta. The north and south forks of the Skagit River are indicated.

APPROACH

Our modeling effort utilizes the Finite Volume Coastal Ocean Model (FVCOM; Chen et al., 2003, 2006), an unstructured-grid, finite-volume numerical model that allows for accurate representation of complicated domains. Flexible, spatially-heterogeneous grids can be constructed so that high spatial resolution is applied only to regions where it is necessary. This flexibility is essential for domains with a wide range of bathymetric scales such as tidal flats and channel networks. A mass-conserving, wetting/drying scheme has been implemented in FVCOM, allowing for flooding/drying processes over tidal flats to be simulated. State-of-the-art two-equation turbulence closure schemes have been implemented in FVCOM using the General Ocean Turbulence Model (GOTM) libraries (Chen et al., 2008). Surface forcing capabilities include wind stress, head flux, and precipitation flux. In addition, the NOPP sponsored Community Sediment Transport Model (CSTM; <http://woodshole.er.usgs.gov/project-pages/sediment-transport>; Warner et al., 2008) has been implemented in FVCOM.

This effort relies on collaborations with other members of the Tidal Flat DRI scientific team. Specifically, we are working with Geoff Cowles (UMASS Dartmouth) and David Ralston (Woods Hole Oceanographic Institution, WHOI) in the development and validation of the Skagit numerical domain as well as in the study of buoyancy driven secondary flows and sediment transport. The data collected by Rocky Geyer, Peter Traykovski and David Ralston (WHOI) over the south Skagit flats are currently being used by Ralston to validate the model.

A goal of this effort over the next year is to collaborate with other researchers studying the Skagit River delta under the DRI via field observations, including Steve Henderson (Univ. Washing.-

Vancouver), Britt Raubenheimer (WHOI), Jim Thomson, and Chris Chickadel (Univ. Washing.-APL). The model provides a temporally and spatially well-resolved simulation of the dynamics driving the circulation over the tidal flats that can be used by the DRI researchers to aid in the dynamical interpretation of their observations.

WORK COMPLETED

The focus of the first year of this two-year project has been on model development and validation. In collaboration with Geoff Cowles and David Ralston, two Skagit River model domains have been developed. A low-resolution grid, with a maximum horizontal resolution over the flats of about 100 m was developed to study tidal dynamics over the flats and to run efficiently on small computation systems (for example, with <10 processors). A high-resolution grid with a maximum horizontal resolution over the flats of about 20 m was also developed (Fig. 2). This grid resolves channel structures over the flats and will be used to study the dynamics driving the three dimensional circulation over the flats.

Model validation of the high-resolution grid, led by Ralston, is underway through comparisons of observations of tidal variations in circulation and stratification over the southern flats collected in June, 2009 (Geyer, Traykovski and Ralston) and realistic numerical simulations of the same period. In addition, we have begun to compute process-oriented simulations to study the tidal dynamics over the flats and to determine the dependence of the three-dimensional circulation and the distribution of buoyancy and stratification over the flats on tidal amplitude, strength of river discharge, and on wind forcing.

RESULTS

The principal accomplishment this year has been the development of a stable, high-resolution, simulation of the Skagit River delta that will subsequently be used to study the dynamics of the circulation over the tidal flats under broad range of forcing regimes and will be used to provide a broad dynamical context to aid in the interpretation of observations collected by other members of the Tidal Flat DRI team.

IMPACT/APPLICATIONS

This modeling effort is testing the capabilities of state-of-the-art hydrodynamic models at simulating the detailed circulation of strongly-forced, bathymetrically complex regions. Such models can be applied to a wide range of applications including the study of: tidal flat morphodynamics; the dynamics of coherent structures observed via remote sensing and their relationship to bottom bathymetry; the influence of sea-level rise on tidal flat dynamics; and the prediction of currents over tidal flats.

RELATED PROJECTS

This effort is being conducted in collaboration with scientists in the Coastal Geosciences Tidal Flats DRI (<http://tidalflats.org/index.html>).

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